

# **Behaviour of Precast Reinforced Concrete Slabs in Steel-Concrete Composite Bridge Decks with Bolted Shear Connectors**

by

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A thesis submitted for the fulfilment of the requirements for the degree of  
**Master of Engineering**



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2014

## **CERTIFICATE OF AUTHORSHIP/ORIGINALITY**

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

*AHMAD RAJABI*

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Sydney, February 2014

## **ACKNOWLEDGEMENTS**

This thesis would not have been completed without the guidance, advice and support of a number of individuals whose contribution I would gratefully like to acknowledge. I would specially like to express my gratitude to my supervisors, Professor Bijan Samali and Dr Hamid Valipour.

I would also like to convey my thanks to University of Technology Sydney (UTS) Civil Engineering Laboratories staff, specially the laboratories manager Mr Rami Haddad, senior project engineer Mr Peter Brown and technical officer Mr David Dicker who kindly helped me in project experimental stages.

Furthermore, I am obliged to many of my colleagues and friends who assisted me during my studies. Special thanks must go to my dear friends and co-researchers, Mr Masoud Moradi for his unfailing assistance and support in this research work.

Lastly, I would like to extend my love and gratitude to my dearest family for their support and encouragement. I want to sincerely thank them from the bottom of my heart and acknowledge that without them none of this could have happened and I was not able to achieve most of the things I have in my life.

Hereby, I would like to dedicate this thesis to my family for being such great supports in my life.

## **LIST OF PUBLICATIONS BASED ON THIS THESIS**

### **Journal Articles**

Rajabi, A., Valipour, H., Samali, B. & Foster, S. 2014, 'Effect of Attenuation Function on the Efficiency and Accuracy of Nonlocal 1D Reinforced Concrete Frame Elements', *Computers and Concrete an International Journal* (Under publication).

### **Conference Papers**

Rajabi, A., Valipour, H., Samali, B. & Foster, S. 2012, 'Application of externally post-tensioned FRP bars for strengthening reinforced concrete members', *22nd Australian Conference on the Mechanics of Structures and Materials*, Sydney, Australia, December 2012 in From materials to structures.

## ABSTRACT

Due to ease of fabrication and maintenance and speed of construction, precast prefabricated composite deck slabs have gained huge popularity all around the globe. The precast prefabricated structural systems do not require the costly in-situ formworks. Accordingly, the precast prefabricated structural systems can reduce the cost of labour and improve the safety and speed of construction. In addition, the prefabricated composite structures can significantly facilitate application of external reinforcement in lieu of conventional internal steel bars. The reinforced concrete (RC) structures, in general, suffer maintenance and repair difficulties, as internal reinforcements in reinforced concrete (RC) structures are susceptible to corrosion that can be typically accelerated by chloride and other corrosive material ingress. Once the corrosion occurs, reinforcement starts to expand inside the concrete and that in turn causes concrete cracking and spalling. Accordingly, the reinforced concrete member cannot perform its structural role properly. Second generation bridge deck slabs, namely steel-free deck slabs, in which conventional embedded reinforcements are replaced by external reinforcements have proved to be efficient in mitigating the problems associated with corrosion of reinforcing steel bars..

The steel-free deck slabs rely on development of arching action to withstand the load. The inherent arching action in longitudinally restrained reinforced concrete members was realised about fifty years ago, however, the beneficial effects of arching action has not been recognised by most of the existing reinforced concrete design standards yet. So far only **Northern Island** Standard, DRD, NI (1990), and **Canadian** code, OHBD (1992) takes account of the enhancing effect of arching action in design practice. This intrinsic capacity of laterally restrained RC structures helps the flexural reinforced concrete members to show loading capacity far in excess of flexural resistance predicted by the conventional formulas.

Apart from corrosion of reinforcing steel bars, the existing steel-concrete composite deck slabs cannot be repaired and rehabilitated conveniently and without the interruption to the traffic. Although many studies have been conducted examining a wide range of composite deck systems, lack of a practical precast prefabricated steel-concrete deck slab that allow for easy replacement of concrete slabs in case of

deterioration is apparent. The restrained steel-free concrete deck provides a practical solution to the corrosion of reinforcement by removing the internal steel bars and replacing them with external steel straps. However, in the meshless slabs proposed by them, the future repair and replacement of concrete slab cannot be conducted easily without a major interruption to the traffic.

To take advantage of the intrinsic characteristic of precast prefabricated deck slabs and to overcome the issues associated with corrosion of internal steel bars in RC bridge decks subject to corrosive environment, a novel steel-concrete deck with precast prefabricated concrete slabs is proposed and examined in this study. The results of experimental tests on precast prefabricated slabs with high strength bolts are presented and FE numerical simulation are carried out using ATENA 2D. The novelty of this research project lies in the application of high strength steel bolts for connecting the concrete slabs to steel girders. The high strength bolts are pre-tensioned with a special amount of tensile force induced in them by a torque meter wrench. This new steel-concrete composite deck has two main advantages; firstly, there is no requirement as to design and assemble formworks for constructing cast-in-situ concrete slabs and hence the construction of deck is much faster. Secondly, the high strength bolts can be opened and the precast slab can be easily released and replaced if required. This advantage allows for easy repair and maintenance of the concrete deck slab without causing significant interruption to the traffic during repair and rehabilitation.

## TABLE OF CONTENTS

Certificate of authorship/originality .....	ii
Acknowledgements .....	iii
List of publications based on this thesis .....	iv
Abstract .....	v
1 Introduction.....	2
1.1 Overview .....	2
1.2 Research significance and contribution.....	3
1.3 Thesis layout.....	4
1.4 Terminologies.....	5
2 Background and literature review .....	8
2.1 Arching action .....	8
2.1.1 Introduction.....	8
2.1.2 Different factors influencing Arching action .....	8
2.1.3 Previous studies.....	10
2.2 Steel-concrete composite structures .....	32
2.2.1 Introduction .....	32
2.2.2 Previous studies.....	34
3 Experimental studies on STEEL-CONCRETE COMPOSITE DECKS WITH precast RC slabs: Behaviour Of RC Slab.....	39
3.1 Introduction .....	39
3.2 Experimental procedure.....	42
3.3 Testing (loading/unloading) procedure .....	63
3.3.1 Sample M6B .....	67
3.3.2 Sample M4B .....	68
3.3.3 Sample B4B .....	70
3.3.4 Sample B6B .....	71
3.3.5 Sample M6SS.....	73
3.3.6 Sample M6S .....	74
3.3.7 Sample M4BS .....	75
3.3.8 Sample M6BS .....	77
3.3.9 Sample B4BS .....	78
3.3.10 Sample B6BS .....	79

4	Analysis of the results and numerical modelling.....	85
4.1	Ductility index and energy-based ductility.....	85
4.1.1	Ductility index.....	86
4.1.2	Energy-based ductility .....	86
4.2	Numerical modeling .....	91
4.2.1	Overview .....	91
4.2.2	Constitutive model SBETA .....	92
4.2.3	Localization limiters.....	104
4.2.4	Fracture process, crack width.....	105
4.2.5	Biaxial stress failure criterion of concrete .....	106
4.2.6	Crack modelling.....	109
4.2.7	Compressive strength of cracked concrete.....	110
4.2.8	Tension stiffening in cracked concrete .....	111
4.2.9	Material stiffness matrices .....	112
4.2.10	Analysis of stresses .....	115
4.2.11	Input parameters for constitutive modelling of materials .....	115
4.3	Finite element analysis (FEA) of samples.....	116
4.3.1	Overview .....	116
4.3.2	Numerical modelling results .....	119
4.3.3	Conclusion .....	123
5	Summary and conclusion.....	126
	REFERENCES.....	130



## LIST OF FIGURES

Figure 2-1. Model demonstration of arching action (simply supported without (i) and with (ii) lateral restraint, (Ockleston, 1958)).	12
Figure 2-2. Yield line mechanism for a two-way slab (Ockleston, 1958).	13
Figure 2-3. Park's geometry of slab strip portion between yield lines (Park and Gamble, 1980).	14
Figure 2-4. Typical theoretical & experimental load-deflection curves for a fixed slab (Wood, 1961).	16
Figure 2-5. Typical theoretical & experimental load-deflection curves for a simple support slab (Wood, 1961).	17
Figure 2-6. Graphical solution for calculating CMA force (Christiansen, 1963).	19
Figure 2-7. Analogy of three-hinged arch (Rankin, 1982).	21
Figure 2-8. prediction of punching shear stress of conventional slab-column specimens (Rankin and Long, 1987a).	22
Figure 2-9. Concept of compressive membrane action in interior slab-column connections (Rankin and Long, 1987b).	23
Figure 2-10. Comparison of the ultimate loading capacity predicted by desing codes with large panel test results (Rankin and Long, 1987b).	24
Figure 2-11. Comparison of the results with US and UK codes (Kirkpatrick et al., 1984a).	26
Figure 2-12. Actual and idealised behaviour of restrained RC member (Rankin and Long, 1997).	27
Figure 2-13. Comparison of test results with some literature (Rankin and Long, 1997).	28
Figure 2-14. Comparison of test results from various sources with predicted failure loads.	30
Figure 2-15. (BS 5400) conditions at ultimate flexural load for NSC ( $f_{cu} < 60Nmm^2$ ) and Taylor (2000) approach.	31
Figure 2-16. Model test load arrangement (Taylor, 2000).	31
Figure 2-17. Various alternatives for transverse confining systems: (a) Fully studded strap; (b) Partially studded strap; (c) Crucisorm strap; (d) Mild steel threaded bar; (e) FRP bar; (f) Diaphragm (Bakht and Mufti, 1996).	35
Figure 3-1. Lateral restraining systems.	41
Figure 3-2. Provision of the moulds for pouring.	43
Figure 3-3. Steel processing apparatuses.	44
Figure 3-4. Uniaxial stress-strain diagram of reinforcing steel bars.	45
Figure 3-5. Fabrication and placing the reinforcing mesh in the mould	46
Figure 3-6. Concrete pouring and slump test.	47

Figure 3-7. Concrete Compressive test. ....	48
Figure 3-8. Instrumentation of the specimens. ....	49
Figure 3-9. Preparation of the steel girders. ....	51
Figure 3-10. Configuration of the web stiffeners. ....	53
Figure 3-11. Torque vs induced pretensioing axial force in a bolt. ....	54
Figure 3-12. Various approaches of tightening the bolts and the corresponding range of induced axial force. ....	56
Figure 3-13. Verifying the performance of torque metre wrench. ....	57
Figure 3-14. Details of the specimens in the push-out tests. ....	59
Figure 3-15. Configuration of slab (samples No. 1-4). ....	60
Figure 3-16. Configuration of slab (samples No. 5-10). ....	61
Figure 3-17. Loading equipment. ....	62
Figure 3-18. Reinforcement arrangements in various samples. ....	64
Figure 3-19. Structural response of sample M6B. ....	67
Figure 3-20. (a) Load-deflection and (b) rotation-deflection graphs for specimen M6B. ....	68
Figure 3-21. Structural response of sample M4B; (a) Connection's rupture, (b) Arching thrust & concrete's crushing. ....	69
Figure 3-22. (a) Load-deflection and (b) rotation-deflection graphs for specimen M4B. ....	70
Figure 3-23. Structural response of sample B4B (Cracks between holes, large deflection and distortion, and formation of arching thrust). ....	70
Figure 3-24. (a) Load-deflection and (b) rotation-deflection graphs for specimen B4B. ....	71
Figure 3-25. Structural response of specimen B6B. ....	72
Figure 3-26. (a) Load-deflection and (b) rotation-deflection graphs for specimen B6B. ....	72
Figure 3-27. (a) Load versus deflection and (b) rotation versus deflection for specimen M6SS. ....	73
Figure 3-28. (a) Load-deflection and (b) rotation-deflection graphs for specimen M6SS. ....	74
Figure 3-29 Structural response of specimen M6S. ....	74
Figure 3-30. (a) Load-deflection and (b) rotation-deflection graphs for specimen M6S. ....	75
Figure 3-31. Structural response of specimen M4BS. ....	76
Figure 3-32. (a) Load-deflection and (b) rotation-deflection graphs for specimen M4BS. ....	76
Figure 3-33. Structural response of sample M6BS. ....	77
Figure 3-34. (a) Load-deflection and (b) rotation-deflection graphs for specimen M6BS. ....	78

Figure 3-35. Structural response of sample B4BS .....	78
Figure 3-36. (a) Load-deflection and (b) rotation-deflection graphs for specimen B4BS. .....	79
Figure 3-37. Structural response of sample B6BS .....	80
Figure 3-38. (a) Load-deflection and (b) rotation-deflection graphs for specimen B6BS. .....	80
Figure 4-1. Definition of toughness index (ACI Committee 544) .....	87
Figure 4-2. Elastic and inelastic energy in beams with different types of tendons .....	87
Figure 4-3. Energy ductility measure in eccentrically loaded columns .....	88
Figure 4-4. Ductility Index concept .....	89
Figure 4-5. Energy ductility concept .....	90
Figure 4-6. Components of plane stress state (Červenka et al., 2012) .....	93
Figure 4-7. Components of plane strain state (Červenka et al., 2012) .....	93
Figure 4-8. Rotation of reference coordinate axes (Červenka et al., 2012) .....	94
Figure 4-9. Concrete uniaxial stress-strain diagram (Červenka et al., 2012) .....	97
Figure 4-10. Linear softening based on strain (Červenka et al., 2012) .....	100
Figure 4-11. Steel fibre reinforced concrete based on fracture energy (Červenka et al., 2012). .....	100
Figure 4-12. Effective stress versus strain for steel fibre reinforced concrete under tension (Červenka et al., 2012). .....	101
Figure 4-13. Outline of the stress-strain diagram for concrete under compression (Červenka et al., 2012). .....	102
Figure 4-14. Softening displacement law for concrete under compression (Červenka et al., 2012). .....	<b>Error! Bookmark not defined.</b>
Figure 4-15. Definition of localization bands (Červenka et al., 2012). .....	105
Figure 4-16. Stages of crack opening (Červenka et al., 2012) .....	106
Figure 4-17. Biaxial failure function for concrete (Červenka et al., 2012) .....	107
Figure 4-18. Tension-compression failure function for concrete (Červenka et al., 2012). .....	109
Figure 4-19. Compressive strength reduction of cracked concrete (Červenka et al., 2012). .....	111
Figure 4-20. Reinforcement arrangement/lateral restraining systems modelled in ATENA 2D- samples M6S and M6SS. ....	117
Figure 4-21. Reinforcement arrangement/lateral restraining systems modelled in ATENA 2D. ....	118
Figure 4-22. Reinforcement arrangement/lateral restraining systems modelled in ATENA 2D. ....	119
Figure 4-23. Numerical & experimental results for sample M6B. ....	120

Figure 4-24. Numerical & experimental results for sample M4B. ....	120
Figure 4-25. Numerical & experimental results for sample B4B. ....	121
Figure 4-26. Numerical & experimental results for sample B6B. ....	121
Figure 4-27. Numerical & experimental results for sample M6SS.....	121
Figure 4-28. Numerical & experimental results for sample M6S.....	122
Figure 4-29. Numerical & experimental results for sample M4BS. ....	122
Figure 4-30. Numerical & experimental results for sample M6BS. ....	122
Figure 4-31. Numerical & experimental results for sample B4BS. ....	123
Figure 4-32. Numerical & experimental results for sample B6BS. ....	123
Figure 5-1. Load-deflection response of RC slabs specimens with the same amount of reinforcing steel bars but with different locations for the reinforcement.....	127
Figure 5-2. Comparison of experimental ultimate loading capacity for all 10 tested specimens. ....	128

## LIST OF TABLES

Table 2-1. Different factors affecting compressive membrane force .....	10
Table 2-2. The reinforcing proportion recommended by Canadian and Northern Island standards for concrete bridge decks. ....	10
Table 2-3. Classification of methods available for predicting CMA .....	11
Table 3-1. Values of $f_y$ from several Tensile test .....	44
Table 3-2. Values of $f_c'$ .....	48
Table 3-3. Instrumentations on slabs .....	49
Table 3-4. Various tightening methods .....	55
Table 3-5. Output of Wrench check-up test .....	58
Table 3-6. Specimen names, bar configuration and transverse stiffnesses .....	66
Table 3-7. Mode of failure for different samples .....	81
Table 3-8. Summary of experimental results. ....	82
Table 3-9. Summary of experimental results (continue) .....	83
Table 4-1. Deformation-based ductility index values for the tested RC slabs .....	89
Table 4-2. Energy-based ductility indices for tested RC slabs. ....	90
Table 4-3. The values of constants related to Equation 57. ....	109
Table 4-4. Default formulas for calculating the material input parameters (Červenka et al., 2012). ....	116
Table 4-5. Specifications and assumptions considered in numerical modelling. ....	120

## NOTATIONS

The symbols used in this thesis, including their definitions, are listed below.

$A$	Cross-sectional area of a rectangular concrete section
$A_s$	Cross-sectional area of reinforcement
$A'_s$	Cross-sectional area of compressive reinforcement
$b$	Width of a rectangular cross-section (width of slab)
$c$	Depth of neutral axis
$C$	Membrane force
$C_c$	Compressive force carried by concrete
$C_s$	Compressive force carried by tensile
$d$	Effective depth (the distance from the extreme fibre to the centroid of the tensile steels)
$D$	Diameter of high strength bolt
$d_b$	Diameter of steel reinforcement
$d_1$	Half of the arching depth
$d'$	Distance from the extreme compressive fibre to the centroid of the compression steels
$e$	Distance from neutral axis
$E$	Modulus of elasticity of steel reinforcement
$E_c$	Modulus of elasticity of concrete
$f_c$	Compressive strength of concrete – stress in concrete
$f'_c$	Characteristic compressive (cylinder) strength of concrete
$E_{tot}$	The total area under the load-deflection diagram up to the failure load (total energy)
$E_{el}$	The elastic energy
$E_{0.75pu}$	The area under the load-deflection diagram up to 0.75% the ultimate load.

$f_{cu}$	Compressive (cube) strength of concrete
$f_{cyl}$	Compressive (cylinder) strength of concrete
$F_t$	Post tensioning force induced in high strength bolt
$f_u$	Specified ultimate strength of steel reinforcement
$f_y$	Specified yield strength of steel reinforcement
$h$	Overall height of a rectangular cross-section
$h_a$	Height of the arch in three-hinged arch theory
$h_1$	Distance between membrane force at hogging and sagging
$I_{10}$	Energy ductility index
$k$	The ratio of the outward movement of the support to elastic shortening of the beam
$k$	Lateral stiffness in a laterally restrained RC member
$K_b$	Equivalent stiffness of support beam
$K_d$	Stiffness of diaphragm and slab
$K_r$	Combined stiffness of restraint
$l$	RC member's span length
$L$	RC member's span length
$L_e$	Half of span length in elastically restrained arch
$L_r$	Half of span length in rigidly restrained arch
$M_a$	Arching moment of resistance
$M_{ar}$	Arching moment of resistance of rigidly of rigidly restrained slab strip
$M_{bal}$	Balanced moment of resistance
$M_r$	Moment ratio (non-dimensional)
$m_u$	Sagging moment in a yielded section
$m'_u$	Hogging moment in a yielded section
$M_b$	Sagging moment in a yielded section

$M_{-b}$	Hogging moment in a yielded section
$n_u$	Difference between compressive and tensile forces in a yielded section
$P$	Applied load
$P_a$	Predicted ultimate arching capacity
$P_b$	Predicted ultimate flexural capacity
$P_j$	Johansen's loads (i.e. flexural capacity using yield line analysis)
$P_m$	Load due to compressive membrane action
$P_p$	Predicted ultimate capacity under Park's method
$P_{test}$	Maximum total load on the slab
$P_{vf}$	Flexural punching strength
$P_{vs}$	Shear punching strength
$R$	McDowell's non-dimensional parameter (elastic deformation)
$t$	Thickness of slab
$T$	Tensile force carried by tensile reinforcement
$T_b$	Torque applied by wrench in high strength bolt
$Q_e$	Effective reinforcement ratio at principal section
$w$	Load/(unit area carried by arching action)
$w$	Deflection under the point load
$\varepsilon_{av}$	Average axial strain in a section
$\varepsilon_0$	Concrete compressive plastic strain
$\varepsilon_u$	Concrete maximum compressive strain
$\xi$	Axial strain
$\kappa$	Beam/column curvature
$\varepsilon$	Strain
$\varepsilon_c$	Plastic strain of idealised elastic-plastic concrete



$\varphi$	Width of circular patch load
$\rho$	Longitudinal tension reinforcement ratio in a section ( $A_s/bd$ )
$\rho_a$	Effective arching reinforcement ratio at principal section
$\rho_e$	Effective reinforcement ratio at principal section
$\mu$	Ductility index (general definition)
$\mu_\phi$	Ductility index in term of curvature
$\mu_\theta$	Ductility index in term of rotation
$\mu_\Delta$	Ductility index in term of deflection
$\mu_E$	Energy ductility index
$\phi$	Curvature
$\phi_u$	Ultimate curvature
$\phi_y$	Yielding curvature
$\theta$	Rotation
$\theta_y$	Rotation at yielding
$\theta_u$	Rotation at ultimate load
$\beta_1$	Ratio of depth of rectangular stress block, $a$ , to depth to neutral axis, $c$
$\delta$	Deflection under the load point
$\Delta$	Deflection at centre of structure member
$\Delta_e$	Mid-span elastic deformation
$\Delta_u$	Ultimate deflection
$\Delta_p$	Mid-span plastic deformation
$\Delta_y$	Yielding deflection